

TITLE OF THE INVENTION

MASK, MANUFACTURING METHOD FOR MASK, AND MANUFACTURING  
METHOD FOR SEMICONDUCTOR DEVICE

CROSS-REFERENCE TO RELATED APPLICATIONS

5           This application is based upon and claims the  
benefit of priority from the prior Japanese Patent  
Application No. 2002-279742, filed September, 25, 2002;  
the entire contents of which are incorporated herein  
by reference.

10                           BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a mask, a  
manufacturing method for a mask, and a manufacturing  
method for a semiconductor device.

15                           2. Description of the Related Art

The inventors have already proposed a focus  
monitor mask used to measure the magnitude of defocus  
in an exposure apparatus including the sign of the  
defocus (refer to Jpn. Pat. Appln. Nos. 11-274701 and  
20   11-375472, which correspond to US Patent. No.6440616).  
FIG. 20 illustrates an example of this focus monitor  
mask. This figure schematically shows a planar  
configuration of a mask pattern formed area.

The mask pattern formed area includes a reference  
25   mark area 10 and a phase shift mark area 20. The  
reference mark area 10 has a surrounding portion  
(surrounding area) 11 including an opaque portion or a

halftone portion and five opening portions (opening areas) 12 surrounded by the surrounding portion 11. The phase shift mark area 20 has a surrounding portion 21 including a halftone portion and five opening portions 22 surrounded by the surrounding portion 21. The opening portions 12 and 22 are used as focus monitor marks and have the same diamond-like (rhomboid-like) planar shape. A phase difference between the opening portions 22 and the surrounding portion 21 is set to be  $90^\circ$ . Accordingly, there is a phase difference of  $90^\circ$  between exposure light passing through the opening portions 22 and exposure light passing through the surrounding portion 21.

The use of a mask configured as described above enables focus monitoring. This focus monitoring utilizes misalignment that may occur between the best focus point for the pattern (reference mark) of the opening portions 12 and the best focus point for the pattern (phase shift mark) of the opening portions 22. A monotonous decrease or increase relative to defocus is observed in a size difference between a long side of the reference mark and a long side of the phase shift mark which difference may occur after exposure or development. Thus, by determining the relationship between defocus and this size difference in the form of a calibration curve and subsequently measuring a size difference on a wafer after exposure and development,

the magnitude of defocus can be monitored including its direction.

FIG. 22 shows the relationship (calibration curve) between a size difference ( $L-L'$ ) and defocus where  $L$  denotes the size of a long side of a reference mark on a wafer and  $L'$  denotes the size of a long side of a phase shift mark on the wafer. A line a indicates the size  $L$  of the reference mark. A line b indicates the size  $L'$  of the phase shift mark. A line c indicates the size difference ( $L-L'$ ). The size difference  $c$  increases monotonously relative to defocus. Accordingly, this calibration curve can be used to determine the magnitude of defocus including its sign. In this connection, varying the magnitude of exposure by  $\pm 10\%$  does not substantially change the calibration curve. Therefore, even with a slight variation in the magnitude of exposure, the defocus can be accurately detected.

Now, description will be given of a manufacturing method for a conventional mask having a pattern such as the one shown in FIG. 20. FIGS. 21A to 21H schematically show cross sections taken along line A-A' in FIG. 20.

First, as shown in FIG. 21A, a quartz substrate is provided as a transparent substrate 101. An  $\text{MoSiO}_x$  film is formed on the transparent substrate 101 as a halftone phase shift film 102. Subsequently, a Cr film

is formed on the halftone phase shift film 102 as an opaque film 103. Furthermore, a chemically amplified positive type resist 104 is applied to the opaque film 103. The halftone phase shift film 102 sets a phase  
5 difference of  $180^\circ$  between exposure light passing through the halftone phase shift film 102 and exposure light passing through the opening portion 12.

Then, as shown in FIG. 21B, focus monitor marks are written in the resist film 104 in a reference mark  
10 area and a phase shift mark area. At this time, device pattern is also written in a device pattern forming area (not shown). Subsequently, the substrate is baked and then development is carried out to form a resist pattern 104.

15 Then, as shown in FIG. 21C, the opaque film 103 and the halftone phase shift film 102 are sequentially etched using the resist pattern 104 as a mask. This etching forms a focus monitor mark pattern corresponding to the planar shape of the opening  
20 portions 12 and 22 as well as a device pattern (not shown). Subsequently, the resist film 104 is removed and the substrate is cleaned.

Then, as shown in FIG. 21D, an i-ray photo resist  
25 151 is applied. Subsequently, to mask the area except for the opening portions of the phase shift mark, a writing operation is performed using a laser writing apparatus. Furthermore, a developer is used to carry

out development to obtain a resist pattern 151.

Then, as shown in FIG. 21E, the transparent substrate 101 is etched using the resist pattern 151 and the opaque film 103 as a mask. This allows the transparent substrate 101 to be etched only in the opening portions of the phase shift mark to form holes 152.

Then, as shown in FIG. 21F, the resist 151 is removed and the substrate is cleaned.

Then, as shown in FIG. 21G, an i-ray photo resist 153 is applied. Subsequently, to mask the opening portions in the reference mark area 10, Cr opaque frame portions, and other Cr pattern portions, the laser writing apparatus is used to write in the resist film 153. Furthermore, a developer is used to carry out development to obtain a resist pattern 153.

Then, as shown in FIG. 21H, the resist pattern 153 is used as a mask to wet-etch the opaque film 103. Subsequently, the resist film 153 is removed and the substrate is cleaned.

A mask configured as shown in FIGS. 20 and 21H is obtained as described above. Since the transparent substrate 101 is etched to form the holes 152, it is possible to give a phase difference of  $-90^\circ$  to exposure light passing through the opening portions in the phase shift mark area 20 relative to exposure light passing through the opening portions in the reference mark

area 10.

However, with the above conventional manufacturing method, extra lithography and etching steps such as those shown in FIGS. 21D to 21F are required to form the holes 152 used to create a phase difference of  $90^\circ$ . This sharply increases the time required for a manufacturing process, thus affecting manufacturing costs and TAT.

Thus, the conventional focus monitor mask requires extra lithography steps to obtain a phase difference of  $90^\circ$ . This increases the time required for the manufacturing process, thus increasing manufacturing costs.

#### BRIEF SUMMARY OF THE INVENTION

According to a first aspect of the present invention, there is provided a mask comprising: a first area including a first surrounding area in which a halftone phase shift film or a stacked film of a halftone phase shift film and an opaque film is provided on a transparent substrate, and a first opening area surrounded by the first surrounding area; and a second area including a second surrounding area in which a halftone phase shift film is provided on the transparent substrate and a second opening area surrounded by the second surrounding area, wherein a transparent film is provided in at least a part of the second opening area, the transparent film being

configured to give a predetermined phase difference to exposure light passing through that part of the second opening area in which the transparent film is provided relative to exposure light passing through the second surrounding area.

According to a second aspect of the present invention, there is provided a mask comprising: a first area including a first surrounding area in which a halftone phase shift film or a stacked film of a halftone phase shift film and an opaque film is provided on a transparent substrate, and a first opening area surrounded by the first surrounding area; and a second area including a second surrounding area in which a halftone phase shift film is provided on the transparent substrate and a second opening area surrounded by the second surrounding area, wherein at least a part of the halftone phase shift film in the second surrounding area is thinner than the halftone phase shift film in the first surrounding area, and is configured to give a predetermined phase difference to exposure light passing through that part of the second surrounding area which includes the thinner part of the halftone phase shift film relative to exposure light passing through the second opening area.

According to a third aspect of the present invention, there is provided a method of manufacturing a mask comprising: providing, in a first area, a first

surrounding area in which a halftone phase shift film  
or a stacked film of a halftone phase shift film and an  
opaque film is provided on a transparent substrate and  
a first opening area surrounded by the first  
5 surrounding area, and, in a second area, a second  
surrounding area in which a halftone phase shift film  
is provided on the transparent substrate and a second  
opening area surrounded by the second surrounding area;  
and forming a transparent film in a selected area  
10 including at least a part of the second opening area,  
and giving a predetermined phase difference to exposure  
light passing through that part of the second opening  
area in which the transparent film is provided relative  
to exposure light passing through the second  
15 surrounding area.

According to a fourth aspect of the present  
invention, there is provided a method of manufacturing  
a mask comprising: providing, in a first area, a first  
surrounding area in which a halftone phase shift film  
20 or a stacked film of a halftone phase shift film and an  
opaque film is provided on a transparent substrate and  
a first opening area surrounded by the first  
surrounding area, and, in a second area, a second  
surrounding area in which a halftone phase shift film  
25 is provided on the transparent substrate and a second  
opening area surrounded by the second surrounding area;  
and supplying an etching source to a selected area



including at least a part of the second opening area to  
etch the transparent substrate in the selected area,  
and giving a predetermined phase difference to exposure  
light passing through that part of the second opening  
5 area which includes the etched part of the transparent  
substrate relative to exposure light passing through  
the second surrounding area.

According to a fifth aspect of the present  
invention, there is provided a method of manufacturing  
10 a mask comprising: providing, in a first area, a first  
surrounding area in which a halftone phase shift film  
or a stacked film of a halftone phase shift film and an  
opaque film is provided on a transparent substrate and  
a first opening area surrounded by the first  
15 surrounding area, and, in a second area, a second  
surrounding area in which a halftone phase shift film  
is provided on the transparent substrate and a second  
opening area surrounded by the second surrounding area;  
and supplying an etching source to a selected area  
20 including at least a part of the second surrounding  
area to etch the halftone phase shift film in the  
selected area, and giving a first phase difference to  
exposure light passing through that part of the second  
surrounding area which includes the etched part of the  
25 halftone phase shift film relative to exposure light  
passing through the second opening area.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWING

FIG. 1 is a diagram schematically showing a planar configuration of a mask pattern formed area in a mask according to embodiments of the present invention;

5        FIGS. 2A to 2F are sectional views showing manufacturing steps for a mask according to a first embodiment of the present invention;

FIG. 3 is a view schematically illustrating a dropping apparatus according to the embodiments of the present invention;

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FIG. 4 is a diagram showing areas in a mask according to the embodiments of the present invention;

FIG. 5 is a sectional view showing a variation of the mask according to the first embodiment of the present invention;

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FIGS. 6A to 6D are sectional views showing manufacturing steps for a mask according to a second embodiment of the present invention;

FIG. 7 is a sectional view showing a variation of the mask according to the second embodiment of the present invention;

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FIGS. 8A to 8D are sectional views showing manufacturing steps for a mask according to a third embodiment of the present invention;

FIG. 9 is a sectional view showing a variation of the mask according to the third embodiment of the present invention;

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FIGS. 10A and 10B are sectional views showing another variations of the masks according to the third embodiment of the present invention;

5        FIGS. 11A to 11D are sectional views showing manufacturing steps for a mask according to a fourth embodiment of the present invention;

FIG. 12 is a sectional view showing a variation of the mask according to the fourth embodiment of the present invention;

10        FIGS. 13A and 13B are sectional views showing another variations of the masks according to the fourth embodiment of the present invention;

15        FIGS. 14A to 14D are sectional views showing manufacturing steps for a mask according to a fifth embodiment of the present invention;

FIG. 15 is a graph showing the relationship between defocus and a size difference according to the fifth embodiment of the present invention;

20        FIG. 16 is a graph showing the relationship between defocus and a size difference;

FIG. 17 is a graph showing the relationship between a phase accuracy and a variation in sensitivity;

25        FIG. 18 is a diagram schematically showing a planar configuration of another example of a mark pattern formed area in a mask according to the embodiments of the present invention;

FIG. 19 is a flow chart showing steps executed if the mask according to the embodiments of the present invention is applied to manufacturing of a semiconductor device;

5           FIG. 20 is a diagram schematically showing a planar configuration of an example of a mark pattern formed area in a mask according to the prior art;

          FIGS. 21A to 21H are sectional views showing manufacturing steps for a mask according to the prior art; and

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          FIG. 22 is a graph showing the relationship between defocus and a size difference.

#### DETAILED DESCRIPTION OF THE INVENTION

Embodiments of the present invention will be described below with reference to the drawings.

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(Embodiment 1)

First, a first embodiment of the present invention will be described.

FIG. 1 is a diagram schematically showing a planar configuration of a mark pattern formed area according to the present embodiment.

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The mark pattern forming area includes a reference mark area 10 and a phase shift mark area 20. The reference mark area 10 has a surrounding portion (surrounding area) 11 comprising an opaque portion or a halftone portion and five opening portions (opening areas) 12 surrounded by the surrounding portion 11.

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The phase shift mark area 20 has a surrounding portion 21 comprising a halftone portion and five opening portions 22 surrounded by the surrounding portion 21. The opening portions 12 and 22 are used as  
5 focus monitor marks and have the same diamond-like (rhomboid-like) planar shape. There is a phase difference of  $90^\circ$  between exposure light passing through the opening portions 22 and exposure light passing through the surrounding portion 21. In the  
10 present example, each opening is  $12\text{ }\mu\text{m}$  in length in the direction of an X axis,  $0.18\text{ }\mu\text{m}$  in width in the direction of a Y axis, and  $0.36\text{ }\mu\text{m}$  in pitch in the direction of the Y axis, in terms of sizes on a wafer.

The mark pattern forming area including the  
15 reference mark area 10 and phase shift mark area 20 may be provided in a device pattern forming area. However, it is preferably located in a dicing area 40 between device pattern forming areas 30 as shown in FIG. 4. By forming the mask pattern forming area in the dicing  
20 area 40, it is possible to avoid an increase in the size of the device pattern forming area 30, in which a real device is to be formed.

Now, with reference to FIGS. 2A to 2F, description will be given of a manufacturing method for a mask  
25 having a pattern such as the one shown in FIG. 1. FIGS. 2A to 2F schematically show cross sections taken along line A-A' in FIG. 1. With the manufacturing

method according to the present embodiment, a pipette and a dropping apparatus are used to apply droplets for an SOG (Spin On Glass) film to the opening portions 22 in the phase shift mark area 20 to form a transparent film in the opening portions 22.

5 First, as shown in FIG. 2A, a quartz substrate of 6 x 6 inches is provided as a transparent substrate 101. An MoSiO<sub>x</sub> film of thickness 100 nm is formed on the transparent substrate 101 as a halftone phase shift film 102. Subsequently, a Cr film of thickness 60 nm is formed on the halftone phase shift film 102 as an opaque film 103. Furthermore, a chemically amplified positive type resist 104 is applied to the opaque film 103 to a thickness of 600 nm. The halftone phase shift film 102 inverses the phase of exposure light incident to the halftone phase shift film 102 to allow the light to exit the film 102. That is, the halftone phase shift film 102 sets a phase difference of 180° between exposure light incident to the halftone phase shift film 102 and exposure light exiting the halftone phase shift film 102. That halftone phase shift film 102 has a transmittance of, for example, 6%.

15 Then, as shown in FIG. 2B, focus monitor marks are written in the resist film 104 in the reference mark area 10 and phase shift mark area 20. At this time, a device pattern is also written in the device pattern forming area (not shown). In this case, an electron

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beam writing apparatus with an acceleration voltage of 50 KeV is used. However, a laser beam writing apparatus or a photo repeater may be used.

Subsequently, the substrate is baked at 120°C for 90  
5 seconds. Then, an alkali developer with a normality of 0.21 is used to carry out spray development for 60 seconds. Thus, a resist pattern 104 is formed.

Then, as shown in FIG. 2C, the opaque film 103 and the halftone phase shift film 102 are sequentially  
10 etched using the resist pattern 104 as a mask. This etching forms a focus monitor mark pattern corresponding to the planar shape of the opening portions 12 and 22 as well as a device pattern (not shown). Subsequently, the resist film 104 is removed  
15 using O<sub>2</sub> ashing and a mixed liquid of sulfuric acid and hydrogen peroxide. Then, the substrate is cleaned.

Then, as shown in FIG. 2D, an i-ray photo resist 105 is applied. Subsequently, to mask the opening portions in the reference mark area 10, Cr opaque frame portions, and other Cr pattern portions, a laser  
20 writing apparatus is used to write in the resist film 105. Furthermore, an alkali developer with a normality of 0.21 is used to carry out spray development for 60 seconds. Thus, a resist pattern 105 is formed.

25 Then, as shown in FIG. 2E, the resist pattern 105 is used as a mask to wet-etch the opaque film 103. Subsequently, the resist film 105 is removed using O<sub>2</sub>

ashing and a mixed liquid of sulfuric acid and hydrogen peroxide. Then, the substrate is cleaned.

Subsequently, as shown in FIG. 2F, as a transparent film 106, an SOG film is formed selectively in that part of the phase shift mark area 20 which includes the opening portions. The SOG film is formed using a dropping apparatus such as the one shown in FIG. 3. The dropping apparatus comprises an auxiliary plate 51 on which a mask plate 52 is placed and a chemical liquid supply nozzle 53 that supplies a chemical liquid to the mask plate 52. The chemical liquid supply nozzle 53 and the mask plate 52 can be relatively moved. By adjusting the positional relationship between the chemical liquid supply nozzle 53 and the mask plate 52, a chemical liquid can be selectively supplied to a target area. This dropping apparatus is used to drop an SOG material liquid in that part of the phase shift mark area 20 which includes the opening portions 22. Subsequently, the substrate is heated at 450°C for 30 minutes and then cleaned.

As described above, a mask configured as shown in FIGS. 1 and 2F is obtained. As a result, it is possible to give a phase difference of +90° to the area in which the transparent film 106 is formed as compared with a reference surface S (an unprocessed part of the surface of the transparent substrate 101).



Specifically, it is possible to give a phase difference of  $+90^\circ$  to exposure light passing through the area in which the transparent film 106 is formed relative to exposure light passing through the opening portion 12 in the reference mark area 10.

Consequently, when the above mask is used to transfer patterns to a wafer (semiconductor substrate), there occurs a size difference between a focus monitor pattern on the wafer corresponding to the opening portions 12 in the reference mark area 10 and a focus monitor pattern on the wafer corresponding to the opening portions 22 in the phase shift mark area 20. As a result, the relationship between the size difference between both patterns and the magnitude of defocus is similar to that shown in the Related Art section with reference to FIG. 22. Thus, as described in the Related Art section, by determining a calibration curve indicative of the relationship between the pattern size difference (the longitudinal size difference between the focus monitor patterns) and the magnitude of defocus and subsequently determining the pattern size difference on the wafer after exposure and development, the magnitude of defocus can be obtained including its direction.

As described above, according to the present embodiment, to obtain a phase difference of  $90^\circ$ , the transparent film 106 is selectively formed at the

opening portions 22 in the phase shift mark area 20.

The transparent film 106 is formed by selectively dropping the material liquid for the transparent film 106 at the opening portions 22. This eliminates the needs for cumbersome photolithographic steps.

Therefore, a precise mask can be formed using simple steps, thus avoiding an increase in manufacturing costs or TAT.

In the above manufacturing steps shown in FIGS. 2A to 2F, described above, the surrounding portion 11 in the reference mark area 10 is formed of an opaque portion in which the stacked film of the halftone phase shift film 102 and opaque film 103 is formed on the transparent substrate 101. However, the surrounding portion 11 may be formed of a halftone portion in which only halftone phase shift film 102 is formed on the transparent substrate 101 with the opaque film 103 omitted.

In this case, when the laser is used to write in the resist film 105 during the step shown in FIG. 2D, the resist 105 in the reference mark area 10 may also be irradiated with laser beams. Then, during a development step, the resist 105 may be removed from the reference mark area 10. In this case, the reference mark area 10 is not masked by the resist. As a result, during the step shown in FIG. 2E, the opaque film 103 in the reference mark area 10 is also etched

to obtain a structure in which the halftone phase shift film 102 is exposed. Then, during the step shown in FIG. 2F, SOG droplets may be applied only to within the phase shift mark area 20. This provides a structure such as the one shown in FIG. 5.

Also in this case, a calibration curve can be obtained which is similar to the one obtained if the opaque film is formed in the reference mark area 10. Accordingly, by determining the size difference between the patterns on the wafer after exposure and development, the magnitude of defocus can be obtained including its direction.

Further, in the present embodiment, the material for the transparent film 106 is an SOG material such as poly methyl siloxane which is easily hardened when heated and which is not degraded even when cleaned with an oxide or irradiated with ultraviolet light. However, other materials may be used provided that they have desired properties.

(Embodiment 2)

Now, a second embodiment of the present invention will be described.

The basic planar configuration of this embodiment is similar to the one shown in FIG. 1 and 4 for the first embodiment. Accordingly, its detailed description is omitted.

With reference to FIGS. 6A to 6D, description will

be given below of a manufacturing method for a mask according to the present embodiment. FIGS. 6A to 6D schematically show cross sections taken along line A-A' in FIG. 1. Components corresponding to the configuration shown FIGS. 2A to 2F for the first embodiment are denoted by the same reference numerals.

With the manufacturing method according to the present embodiment, the pipette and the dropping apparatus are used to drop a wet etchant in the opening portions 22 in the phase shift mark area 20 to form holes in the opening portions 22 of the transparent substrate 101.

First, a structure such as the one shown in FIG. 6A is formed by executing steps similar to those shown in FIGS. 2A to 2D for the first embodiment.

Then, as shown in FIG. 6B, the resist pattern 105 is used as a mask to wet-etch the opaque film 103. Subsequently, the resist film 105 is removed using O<sub>2</sub> ashing and a mixed liquid of sulfuric acid and hydrogen peroxide. Then, the substrate is cleaned.

Then, as shown in FIG. 6C, a wet etchant 111 is selectively dropped in that area of the phase shift mark area 20 which includes the opening portions. The substrate is then cleaned. The dropping apparatus used for the wet etchant 111 may have a basic configuration similar to that of the apparatus shown in FIG. 3 for the first embodiment. Specifically, this dropping

apparatus is used to drop the wet etchant through the chemical liquid supply nozzle selectively in that area of the phase shift mark area 20 which includes the opening portions 22.

5           As shown in FIG. 6D, the above etching step forms selectively forms holes 112 in those areas of the phase shift mark area 20 each of which includes the opening portion 22. The depth of the holes 112 can be adjusted on the basis of the time elapsing after the wet etchant  
10           has been dropped and before a rinse liquid is dropped. The wet etchant may be a 20% diluent of  $\text{NH}_4\text{F}$ , and the rinse liquid may be water.

          As described above, a mask configured as shown in FIGS. 1 and 6D is obtained. As a result, it is  
15           possible to give a phase difference of  $-90^\circ$  to the area in which the hole 112 is formed as compared with a reference surface S. Specifically, it is possible to give a phase difference of  $-90^\circ$  to exposure light passing through the area in which the hole 112 is  
20           formed relative to exposure light passing through the opening portion 12 in the reference mark area 10.

          Consequently, when the above mask is used to transfer patterns to a wafer (semiconductor substrate), there occurs a size difference between a focus monitor  
25           pattern on the wafer corresponding to the opening portions 12 in the reference area 10 and a focus monitor pattern on the wafer corresponding to the

opening portions 22 in the phase shift mark area 20.  
Thus, as already described, by determining a  
calibration curve indicative of the relationship  
between the pattern size difference and the magnitude  
of defocus and subsequently determining the pattern  
size difference on the wafer after exposure and  
development, the magnitude of defocus can be obtained  
including its direction.

As described above, according to the present  
embodiment, to obtain a phase difference of  $90^\circ$ , the  
holes 112 are selectively formed in the opening  
portions 22 in the phase shift mark area 20. The holes  
112 are formed by selectively dropping the wet etchant  
at the opening portions 22. This eliminates the needs  
for cumbersome photolithographic steps. Therefore, a  
precise mask can be formed using simple steps, thus  
avoiding an increase in manufacturing costs or TAT.

In the above manufacturing steps shown in FIGS. 6A  
to 6D, described above, the surrounding portion 11 in  
the reference mark area 10 is formed of an opaque  
portion in which the stacked film of the halftone phase  
shift film 102 and opaque film 103 is formed on the  
transparent substrate 101. However, the surrounding  
portion 11 may be formed of a halftone portion in which  
the halftone phase shift film 102 is formed on the  
transparent substrate 101 with the opaque film 103  
omitted.

In this case, when the laser is used to write in the resist film 105 during the step shown in FIG. 6A, the resist 105 in the reference mark area 10 may also be irradiated with laser beams. Then, during a development step, the resist 105 may be removed from the reference mark area 10. In this case, the reference mark area 10 is not masked by the resist. As a result, during the step shown in FIG. 6B, the opaque film 103 in the reference mark area 10 is also etched to obtain a structure in which the halftone phase shift film 102 is exposed. Then, during the step shown in FIG. 6C, the wet etchant may be applied only to within the phase shift mark area 20. This provides a structure such as the one shown in FIG. 7.

Also in this case, a calibration curve can be obtained which is similar to the one obtained if the opaque film is formed in the reference mark area 10. Accordingly, by determining the size difference between the patterns on the wafer after exposure and development, the magnitude of defocus can be obtained including its direction.

Further, in the present embodiment, when the hole 112 is formed,  $\text{NH}_4\text{F}$  is used as the wet etchant, and water is used as the rinse liquid. However, other etchants or rinse liquids may be used provided that they have desired properties.

(Embodiment 3)

Now, a third embodiment of the present invention will be described.

The basic planar configuration of this embodiment is similar to the one shown in FIG. 1 and 4 for the first embodiment. Accordingly, its detailed description is omitted.

With reference to FIGS. 8A to 8D, description will be given below of a manufacturing method for a mask according to the present embodiment. FIGS. 8A to 8D schematically show cross sections taken along line A-A' in FIG. 1. Components corresponding to the configuration shown FIGS. 2A to 2F for the first embodiment are denoted by the same reference numerals.

With the manufacturing method according to the present embodiment, the opening portions 22 in the phase shift mark area 20 are etched by irradiation with charged particles such as ion beams, to form holes in the opening portions 22 of the transparent substrate 122.

First, a structure such as the one shown in FIG. 8A is formed by executing steps similar to those shown in FIGS. 2A to 2D for the first embodiment.

Then, as shown in FIG. 8B, the resist pattern 105 is used as a mask to wet-etch the opaque film 103. Subsequently, the resist film 105 is removed using O<sub>2</sub> ashing and a mixed liquid of sulfuric acid and hydrogen peroxide. Then, the substrate is cleaned.



Then, as shown in FIG. 8C, an FIB (Focused Ion Beam) processing apparatus is used to irradiate the areas corresponding to the opening portions in the phase shift mark area 10 with Ga ion beams 121 to etch the transparent substrate 101. Ga ion irradiation conditions are, for example, an acceleration voltage (the energy of ion beams) of 20 kV and a current of 15 pA. If quartz has a refractive index of 1.508, an etching depth required to change the phase of exposure light of wavelength 248 nm by  $90^\circ$  is 122 nm. The amount of ion beams required to obtain this depth is  $5.7 \times 10^{-2} \text{C/cm}^2$ . To set an irradiated area, the inventors irradiated a 20- $\mu\text{m}$  square area including the mark portions with ion beams and observed secondary electron images to determine automatically the quartz substrate portion and the halftone portion. The amount of ion beams applied during observations is much smaller than that of ion beams required to etch the quartz substrate.

As shown in FIG. 8D, the above ion beam irradiating step forms holes 122 corresponding to the opening portions in the phase shift mark area 20.

As described above, a mask configured as shown in FIGS. 1 and 8D is obtained. As a result, it is possible to give a phase difference of  $-90^\circ$  to the area in which the hole 122 is formed as compared with a reference surface S. Specifically, it is possible to

give a phase difference of  $-90^\circ$  to exposure light passing through the area in which the hole 122 is formed relative to exposure light passing through the opening portion 12 in the reference mark area 10.

5           Consequently, when the above mask is used to transfer patterns to a wafer (semiconductor substrate), there occurs a size difference between a focus monitor pattern on the wafer corresponding to the opening portions 12 in the reference area 10 and a focus  
10          monitor pattern on the wafer corresponding to the opening portions 22 in the phase shift mark area 20. Thus, as already described, by determining a calibration curve indicative of the relationship between the pattern size difference and the magnitude  
15          of defocus and subsequently determining the pattern size difference on the wafer after exposure and development, the magnitude of defocus can be obtained including its direction.

          As described above, according to the present  
20          embodiment, to obtain a phase difference of  $90^\circ$ , the holes 122 are selectively formed at the opening portions 22 in the phase shift mark area 20. The holes 122 are formed by selectively irradiating the opening portions 22 with charged particles such as ion beams.  
25          This eliminates the needs for cumbersome photolithographic steps. Therefore, a precise mask can be formed using simple steps, thus avoiding an increase

in manufacturing costs or TAT.

In the above embodiment, the step of forming the holes 122 as shown in FIGS. 8C and 8D may be executed before the step shown in FIG. 8A (after the step shown in FIG. 2C) or after the step shown in FIG. 8A (before the step shown in FIG. 8B).

Further, in the above embodiment, if the holes 122 are formed using ion beams, the entire area including the five opening portions 22 in the phase shift mark area 20 may be irradiated with ion beams. However, an area including at least a part of each opening portion 22 has only to be irradiated with ion beams. FIGS. 10A and 10B show such an example. An area including the tips of the opening portions 22 may be an ion beam irradiation area 25. In this case, the effects of the focus monitor can also be produced. Specifically, it is sufficient to form holes each extending up to about 6  $\mu\text{m}$  from the tip of the monitor mark.

Further, in the above manufacturing steps shown in FIGS. 8A to 8D, described above, the surrounding portion 11 in the reference mark area 10 is formed of an opaque portion in which the stacked film of the halftone phase shift film 102 and opaque film 103 is formed on the transparent substrate 101. However, the surrounding portion 11 may be formed of a halftone portion in which the halftone phase shift film 102 is formed on the transparent substrate 101 with the opaque

film 103 omitted.

In this case, when the laser is used to write in the resist film 105 during the step shown in FIG. 8A, the resist 105 in the reference mark area 10 may also be irradiated with laser beams. Then, during a development step, the resist 105 may be removed from the reference mark area 10. In this case, the reference mark area 10 is not masked by the resist. As a result, during the step shown in FIG. 8B, the opaque film 103 in the reference mark area 10 is also etched to obtain a structure in which the halftone phase shift film 102 is exposed. Then, during the step shown in FIG. 8C, the ion beam may be applied only to within the phase shift mark area 20. This provides a structure such as the one shown in FIG. 9.

Also in this case, a calibration curve can be obtained which is similar to the one obtained if the opaque film is formed in the reference mark area 10. Accordingly, by determining the size difference between the patterns on the wafer after exposure and development, the magnitude of defocus can be obtained including its direction.

(Embodiment 4)

Now, a fourth embodiment of the present invention will be described.

The basic planar configuration of this embodiment is similar to the one shown in FIG. 1 and 4 for the

first embodiment. Accordingly, its detailed description is omitted.

With reference to FIGS. 11A to 11D, description will be given below of a manufacturing method for a mask according to the present embodiment. FIGS. 11A to 11D schematically show cross sections taken along line A-A' in FIG. 1. Components corresponding to the configuration shown FIGS. 2A to 2F for the first embodiment are denoted by the same reference numerals.

With the manufacturing method according to the present embodiment, the surrounding portion 21 of the phase shift mark area 20 is etched by irradiation with charged particles such as ion beams, to reduce the thickness of the halftone phase shift film 102 in the surrounding portion 21.

First, a structure such as the one shown in FIG. 11A is formed by executing steps similar to those shown in FIGS. 2A to 2D for the first embodiment.

Then, as shown in FIG. 11B, the resist pattern 105 is used as a mask to wet-etch the opaque film 103. Subsequently, the resist film 105 is removed using O<sub>2</sub> ashing and a mixed liquid of sulfuric acid and hydrogen peroxide. Then, the substrate is cleaned.

Then, as shown in FIG. 11C, the FIB processing apparatus is used to irradiate selectively an area including a part of the surrounding portion of the phase shift mark area 20, with Ga ion beams 131. Thus,

the halftone phase shift film 102 is etched. The Ga  
ion irradiation conditions are, for example, an  
acceleration voltage (the energy of ion beams) of 20 kV  
and a current of 15 pA. The etching depth is 50 nm,  
5 which is half the thickness of the halftone phase shift  
film 102, 100 nm. The amount of ion beams required to  
obtain this depth is  $7.7 \times 10^{-3} \text{C/cm}^2$ . To set an  
irradiation area, the inventors irradiated a 20-um  
square area including the mark portions with ion beams  
10 and observed secondary electron images to determine  
automatically the quartz substrate portion and the  
halftone portion. The amount of ion beams applied  
during observations is much smaller than that of ion  
beams required to etch the halftone phase shift film.

15 As shown in FIG. 11D, the above ion beam  
irradiating step forms thinner parts 102a of the  
halftone phase shift film 102, in the part of the  
surrounding portion of the phase shift mark area 20.

As described above, a mask configured as shown in  
20 FIGS. 1 and 11D is obtained. As a result, it is  
possible to give a phase difference of  $90^\circ$  ( $+90^\circ$  or  
 $-90^\circ$ ; in the description below,  $+90^\circ$  will be used) to  
the thinner part 102a of the halftone phase shift film  
102 as compared with a reference surface S. Further,  
25 the halftone phase shift film 102 provides a phase  
difference of  $180^\circ$ . Accordingly, if the reference is  
the phase of exposure light passing through the area in

which the thickness of the halftone phase shift film 102 has not been reduced, the phase of exposure light passing through the thinner part 102a of the halftone phase shift film is  $-90^\circ$ . On the other hand, if the reference is the phase of exposure light passing through the opening portion 12 in the reference mark area 10, the phase of exposure light passing through the thinner part 102a of the halftone phase shift film is  $+90^\circ$ .

Consequently, when the above mask is used to transfer patterns to a wafer (semiconductor substrate), there occurs a size difference between a focus monitor pattern on the wafer corresponding to the opening portions 12 in the reference mark area 10 and a focus monitor pattern on the wafer corresponding to the opening portions 22 in the phase shift mark area 20. Thus, as already described, by determining a calibration curve indicative of the relationship between the pattern size difference and the magnitude of defocus and subsequently determining the pattern size difference on the wafer after exposure and development, the magnitude of defocus can be obtained including its direction.

As described above, according to the present embodiment, to obtain a phase difference of  $90^\circ$ , the thinner parts 102a of the halftone phase shift film are formed adjacent to the respective opening portions 22,

in the surrounding portion 21 of the phase shift mark area 20. The thinner parts 102a are formed by selective irradiation with charged particles such as ion beams. This eliminates the needs for cumbersome photolithographic steps. Therefore, a precise mask can be formed using simple steps, thus avoiding an increase in manufacturing costs or TAT.

In the above embodiment, if ion beams are used to form the thinner parts 102a of the halftone phase shift film, the outside area of the five opening portions 22 in the phase shift mark area 20 may be entirely irradiated with ion beams. However, at least a part of the outside area of each opening portion 22 has only to be irradiated with ion beams. FIGS. 13A and 13B show such an example. An area corresponding to the outside of the tips of the opening portions 22 may be the ion beam irradiation area 25. In this case, the effects of the focus monitor can also be produced. Specifically, it is sufficient to process the halftone phase shift film up to about 6  $\mu\text{m}$  from the tips of the marks.

Further, in the above embodiment, only the halftone phase shift film 102 in the phase shift mark area 20 is selectively etched by irradiation with ion beams. However, the quartz substrate may be simultaneously irradiated with ion beams. However, since the quartz substrate is simultaneously etched, the halftone phase shift film must be etched by more



than 50 nm before a phase difference of  $90^\circ$  can be obtained. The etching depth may be set in view of differences in etching speed and refractive index between the halftone phase shift film and the quartz substrate.

Furthermore, in the above manufacturing steps shown in FIGS. 11A to 11D, described above, the surrounding portion 11 in the reference mark area 10 is formed of an opaque portion in which the stacked film of the halftone phase shift film 102 and opaque film 103 is formed on the transparent substrate 101. However, the surrounding portion 11 may be formed of a halftone portion in which the halftone phase shift film 102 is formed on the transparent substrate 101 with the opaque film 103 omitted.

In this case, when a pattern is written in the resist film 105 during the step shown in FIG. 11A, the resist 105 in the reference mark area 10 may also be irradiated with laser beams. Then, during a development step, the resist 105 may be removed from the reference mark area 10. In this case, the reference mark area 10 is not masked by the resist. As a result, during the step shown in FIG. 11B, the opaque film 103 in the reference mark area 10 is also etched to obtain a structure in which the halftone phase shift film 102 is exposed. Then, during the step shown in FIG. 11C, ion beams have only to be applied to that

part of the phase shift mark area 20 in which the halftone phase shift film 102 is to be made thinner. This provides a structure such as the one shown in FIG. 12.

5           Also in this case, a calibration curve can be obtained which is similar to the one obtained if the opaque film is formed in the reference mark area 10. Accordingly, by determining the size difference between the patterns on the wafer after exposure and  
10           development, the magnitude of defocus can be obtained including its direction.

(Embodiment 5)

Now, a fifth embodiment of the present invention will be described.

15           The basic planar configuration of this embodiment is similar to the one shown in FIG. 1 and 4 for the first embodiment. Accordingly, its detailed description is omitted.

20           With reference to FIGS. 14A to 14D, description will be given below of a manufacturing method for a mask according to the present embodiment. FIGS. 14A to 14D schematically show cross sections taken along line A-A' in FIG. 1. Components corresponding to the configuration shown FIGS. 2A to 2F for the first  
25           embodiment are denoted by the same reference numerals.

With the manufacturing method according to the present embodiment, for one of the reference mark area

10 and the phase shift mark area 20, the opening portions are etched using ion beams. For the other, the halftone phase shift film is etched around each opening portion using ion beams.

5           First, a structure such as the one shown in FIG. 14A is formed by executing steps similar to those shown in FIGS. 2A to 2D for the first embodiment. However, in the present embodiment, no resist patterns are formed in the reference mark area 10.

10           Then, as shown in FIG. 14B, a resist pattern (not shown) in a device pattern forming area (not shown) is used as a mask to wet-etch the opaque film 103. Subsequently, the resist pattern is removed using O<sub>2</sub> ashing and a mixed liquid of sulfuric acid and hydrogen  
15           peroxide. Then, the substrate is cleaned.

          Then, as shown in FIG. 14C, the FIB processing apparatus is used to irradiate the areas corresponding to the opening portions in the phase shift mark area 10 with Ga ion beams 141 to etch the transparent substrate  
20           101. The Ga ion irradiation conditions are, for example, an acceleration voltage (the energy of ion beams) of 20 kV and a current of 15 pA. If quartz has a refractive index of 1.508, an etching depth required to change the phase of exposure light of wavelength 248  
25           nm by 90° is 122 nm. The amount of ion beams required to obtain this depth is  $5.7 \times 10^{-2} \text{C/cm}^2$ . To set an irradiation area, the inventors irradiated a 20-um

square area including the mark portions with ion beams  
and observed secondary electron images to determine  
automatically the quartz substrate portion and the  
halftone portion. The amount of ion beams applied  
during observations is much smaller than that of ion  
beams required to etch the quartz substrate. The  
present step forms holes 142 corresponding  
to the opening portions in the reference mark area 10.

Then, as shown in FIG. 14D, the FIB processing  
apparatus is used to irradiate selectively an area  
including a part of the surrounding portion of the  
phase shift mark area, with Ga ion beams 143. Thus,  
the halftone phase shift film 102 is etched. The Ga  
ion irradiation conditions are, for example, an  
acceleration voltage (the energy of ion beams) of 20 kV  
and a current of 15 pA. The etching depth is 50 nm,  
which is half the thickness of the halftone phase shift  
film 102, 100 nm. The amount of ion beams required to  
obtain this depth is  $7.7 \times 10^{-3} \text{C/cm}^2$ . To set an  
irradiated area, the inventors irradiated a 20-um  
square area including the mark portions with ion beams  
and observed secondary electron images to determine  
automatically the quartz substrate portion and the  
halftone portion. The amount of ion beams applied  
during observations is much smaller than that of ion  
beams required to etch the halftone phase shift film.  
The present step forms the thinner parts 102a of the

halftone phase shift film 102, in the part of the surrounding portion of the phase shift mark area 20.

As described above, a mask configured as shown in FIGS. 1 and 14D is obtained. As a result, it is possible to give a phase difference of  $90^\circ$  ( $+90^\circ$  or  $-90^\circ$ ; in the description below,  $-90^\circ$  will be used) to the area in which the hole 142 is formed as compared with a reference surface S. Further, it is possible to give a phase difference of  $90^\circ$  ( $+90^\circ$  or  $-90^\circ$ ; in the description below,  $+90^\circ$  will be used) to the thinner part 102a of the halftone phase shift film 102 as compared with a reference surface S.

In the above example, after the holes 142 have been formed during the step shown in FIG. 14C, the thinner parts 102a of the halftone phase shift film 102 are formed during the step shown in FIG. 14D. However, the holes 142 may be formed after the formation of the thinner parts 102a of the halftone phase shift film 102.

In this manner, in the present embodiment, in those parts of the reference mark area 10 in which the holes 142 are formed, the phase shift is  $-90^\circ$ . On the other hand, in the thinner parts 102a of the phase shift mark area 20, the phase shift is  $+90^\circ$ . That is, the phase shift direction in the former parts is opposite to that in the latter parts. This serves to double sensitivity compared to the first to fourth

embodiments.

FIG. 15 indicates the above matter. This figure shows the relationship (calibration curve) between a size difference ( $L-L'$ ) and defocus where  $L$  denotes the size of a long side of a reference mark on a wafer and  
5  $L'$  denotes the size of a long side of a phase shift mark on the wafer. A line  $a$  indicates the size  $L$  of the reference mark. A line  $b$  indicates the size  $L'$  of the phase shift mark. A line  $c$  indicates the size difference ( $L-L'$ ). A comparison with FIG. 22 indicates  
10 that the present embodiment almost doubles the sensitivity.

Consequently, also in the present embodiment, when the above mask is used to transfer patterns to a wafer  
15 (semiconductor substrate), there occurs a size difference between a focus monitor pattern on the wafer corresponding to the opening portions 12 in the reference mark area 10 and a focus monitor pattern on  
the wafer corresponding to the opening portions 22 in  
20 the phase shift mark area 20. Thus, as already described, by determining a calibration curve indicative of the relationship between the pattern size difference and the magnitude of defocus and  
subsequently determining the pattern size difference on  
25 the wafer after exposure and development, the magnitude of defocus can be obtained including its direction.

As described above, according to the present

embodiment, the holes 142 are formed in the opening portions 12 in the reference mark area 10, whereas the thinner parts 102a of the half tone phase shift film is formed adjacent to the respective opening portion 22, in the surrounding portion 21 of the phase shift mark area 20. These holes 142 and thinner parts 102a are formed by irradiation with charged particles such as ion beams. This eliminates the needs for cumbersome photolithographic steps. Therefore, a precise mask can be formed using simple steps, thus avoiding an increase in manufacturing costs or TAT.

In the above embodiment, the step of forming the holes 142 as shown in FIG. 14C may be executed before the step shown in FIG. 14A (after the step shown in FIG. 2C) or after the step shown in FIG. 14A (before the step shown in FIG. 14B).

Further, many changes may be made to the ion beam irradiation area according to the present embodiment as described in the third and fourth embodiments.

In the above embodiment, when the thinner parts 102a of the halftone phase shift film are formed, only the halftone phase shift film 102 in the phase shift mark area 20 is selectively etched by irradiation with ion beams. However, the quartz substrate may be simultaneously irradiated with ion beams. However, since the quartz substrate is simultaneously etched, the halftone phase shift film must be etched by more

than 50 nm before a phase difference of  $90^\circ$  can be obtained. The etching depth may be set in view of differences in etching speed and refractive index between the halftone phase shift film and the quartz substrate.

Further, in the third to fifth embodiments, if the FIB is used to etch the quartz substrate 101 or the halftone phase shift film 102, the quartz substrate 101 or the halftone phase shift film 102 may be irradiated with Ga ions in a vacuum. However, the quartz substrate 101 or the halftone phase shift film 102 may be etched by irradiation with Ga ions in a gas atmosphere containing, for example, F (fluorine), Cl (chlorine), Br (bromine), or I (iodine).

Further, in the third to fifth embodiments, electromagnetic waves such as laser beams may be used in place of ion beams. An etching operation may be performed, for example, on the basis of laser ablation using a processing apparatus having a laser light source of a triple harmonic (wavelength: 351 nm) of a YAG laser. In particular, if the halftone phase shift film is etched in the fourth and fifth embodiments, the quartz substrate is not substantially etched because the quartz absorbs little laser light. Accordingly, even if the halftone phase shift film and the quartz substrate are simultaneously irradiated with laser beams, it is possible to etch only the halftone phase



shift film selectively.

Further, actual mask manufacturing involves a step of correcting a mask defect found during a mask defect inspecting step. This correcting step uses an FIB apparatus or a laser processing apparatus. Thus, in the third to fifth embodiments, the mask manufacturing process can be made more efficient by continuously executing a etching step and a defect correcting step using ion beams or the like.

Furthermore, in the first to fifth embodiments, the absolute value of a phase difference between exposure light passing through the surrounding portion of the phase shift mark area and exposure light passing through the opening portions in the phase shift mark area is  $90^\circ$ . However, the phase difference is not limited to  $90^\circ$ .

FIG. 16 shows the relationship between defocus and a size difference which relationship is observed when the phase difference is varied. This figure shows that lines indicative of phase differences of  $60^\circ$ ,  $90^\circ$ , and  $120^\circ$  have an almost fixed inclination. Further, a line indicative of a phase difference of  $150^\circ$  has a smaller inclination than the above lines but indicates a tendency to increase monotonously.

FIG. 17 shows the relationship between phase accuracy and a variation in sensitivity which relationship is observed when the phase difference is

set at  $90^\circ$  . Specifically, the axis of abscissa and the axis of ordinate indicate the magnitude of phase errors and the magnitude of a variation in sensitivity, respectively, observed if the phase difference is set at  $90^\circ$  . This figure indicates that the magnitude of a variation in sensitivity increases rapidly when the phase accuracy is  $30^\circ$  or more.

Thus, the phase difference is desirably at least  $60^\circ$  and at most  $150^\circ$  , more preferably at least  $60^\circ$  and at most  $120^\circ$  .

Further, in the first to fifth embodiments, the sizes of the focus monitor mark transferred to the wafer may be measured using an optical line width measuring instrument independent of the exposure apparatus, a line width measuring function contained in the exposure apparatus itself, or a measuring apparatus such as an SEM which is not optical.

Furthermore, the focus monitor marks have only to be measurable using a line width measuring means. These marks may be shaped like, for example, wedges as shown FIG. 18. In short, the focus monitor marks have only to constitute a pattern having a width (a length in a short axis direction) decreasing from center to end or from one end to other end.

Moreover, the size and pitch of the focus monitor marks, the transmittance of the halftone phase shift film, and the like are also not limited to the above

embodiments. They may be varied depending on exposure conditions used or the like.

(Embodiment 6)

5       The present embodiment relates to a manufacturing method for a semiconductor device using a mask such as the one described in the first to fifth embodiments. The present embodiment will be described below with reference to the flow chart shown in FIG. 19.

10       A mask is set on the exposure apparatus (S1). Subsequently, the set mask is used to execute an exposure process to transfer a pattern to resist on a wafer (semiconductor substrate) (S2). Furthermore, the resist is developed (S3). Then, for a resist pattern  
15       resulting from the development process, measurements are made of the sizes of a focus monitor mark pattern corresponding to opening portions in a reference mark area and of a focus monitor mark pattern corresponding to opening portions in a phase shift mark area (S4). Subsequently, the size difference between these  
20       patterns is determined (S5). Subsequently, the magnitude of defocus corresponding to the size difference obtained is determined on the basis of a previously determined calibration curve (S6).

25       The above process is executed on a predetermined number of wafers in a certain lot. The average value of the magnitude of defocus is determined to be the magnitude of defocus for that lot. Then, the focus

position of the exposure apparatus is corrected on the basis of the average magnitude of defocus (S7).

Subsequently, the pattern is transferred to wafers in the subsequent lot using the exposure apparatus with its focus position corrected as well as the above wafer (S8).

By executing the above process on each lot, the lot can always be processed using the optimum focus position. This enables the improvement of the yield and characteristics of semiconductor devices.

The focus position of a device pattern may differ from the focus position of focus monitor marks owing to aberration in the exposure apparatus, the shape of a base for the device pattern, or the like. In such a case, it is possible to feed back the magnitude of defocus determined taking such offset values characteristic of the device into account.

Additional advantages and modifications will readily occur to those skilled in the art. Therefore, the invention in its broader aspects is not limited to the specific details and representative embodiments shown and described herein. Accordingly, various modifications may be made without departing from the spirit or scope of the general inventive concept as defined by the appended claims and their equivalents.